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Rhizobacterial-plant interactions: Strategies ensuring plant growth promotion under drought and salinity stress

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ABSTRACT

Drought and salinity are major environmental stresses resulting in secondary stresses such as osmotic and oxidative stress (common to both stresses) as well as ionic stress (during salinity) causing alterations in physiological, biochemical and molecular processes in plants resulting in substantial loss to crop productivity. The major physiological parameters studied in plants during stressed conditions are malondialdehyde (MDA) content and relative electrical conductivity in leaves, relative water content (RWC), stomatal conductance (gs), Chl content and Chl-fluorescence. Plants inoculated with plant growth promoting rhizobacteria (PGPR) induce morphological and biochemical modifications resulting in enhanced tolerance to abiotic stresses defined as induced systemic tolerance (IST). Molecular approaches such as RNA differential display (RNA-DD), reverse transcriptase PCR (RT-PCR) microarray analysis, real time PCR, differential display PCR (DD-PCR) and illumina sequencing revealed PGPR inoculation caused upregulation of drought stress related genes such as *ERD15* (Early Response to Dehydration 15) and ABA-responsive gene, *RAB18* in *Arabidopsis* genes, *APX1* (ascorbate peroxidise), *SAMS1* (S-adenosyl-methionine synthetase), and *HSP17.8* (heat shock protein) in leaves of wheat, *Cadhn* (dehydrin-like protein), *VA* (Vacuolar ATPase), *sHSP* (Plant small heat shock proteins) and *CaPR-10* (Pathogenesis-related proteins) in pepper, dehydration responsive element binding protein (*DREB2A*), catalase (*CAT1*) and dehydrin (*DHN*) in mung, salt stress responsive genes such as *RAB18* (LEA), *RD29A*, *RD29B* regulons of ABRE (ABA-responsive elements) and DRE (dehydration responsive element) in *Arabidopsis*.

Contents

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1. Introduction

World population is increasing at an alarming rate and sufficient food production is a major challenge for the 21st century. However chemical fertilizers used in intensive agriculture to increase crop productivity creates serious environmental and health hazards. This is even more aggravated by climate change that causes environmental stresses such as drought and salinity which are major deterrents to plant growth responsible for decreased agricultural productivity (Zhang et al., 2010). Water deficit caused by drought lowers soil water potential, causing cell dehydration ultimately inhibiting cell expansion and cell division, thus resulting in osmotic stress (Fig. 1). In addition reactive oxygen species (ROS) produced during drought causes oxidative stress in plants (Vurukonda et al., 2016). Salinity in early phase creates water deficit conditions as higher ionic concentration alters the basic texture of the soil causing decreased soil porosity and subsequently reducing water uptake. Salinity creates osmotic stress thus it can be considered a form of a physiological drought however later higher accumulation of salts in transpiring leaves causes ionic toxicity in plants inducing leaf senescence (Munns and Tester, 2008). Thus cross talks occur between components of drought and salinity stress resulting in secondary stresses such as osmotic and oxidative stress (common to both) as well as ionic stress (during salinity) responsible for plant demise (Gill and Tuteja, 2010). The use of beneficial microbes as an integral component of agricultural practice is technology which should be endorsed to enhance crop productivity in a sustainable and environmentally friendly manner under environmental stress conditions (Gill et al., 2016).

Plant growth promoting rhizobacteria (PGPR) commonly known as rhizobacteria encompasses bacteria inhabiting rhizosphere and facilitating plant growth either through direct mechanisms which include production of phytohormones, enhanced availability of nutrients or by indirect mechanisms that include suppression of pathogens by antibiosis, synthesis of lytic enzymes and induced systemic resistance (ISR) (Glick, 2014). Plant growth promotory activities of rhizobacteria have been reported during drought stress in maize (Vardharajula et al., 2010), cucumber (Wang et al., 2012), mung bean (Sarma and Saikia, 2014) as well during salinity stress in tomato (Mayak et al., 2004), maize (Bano and Fatima, 2009), wheat (Tiwari et al., 2011) and white clover (Han et al., 2014). PGPR induces salt and drought stress tolerance in plants through elicitation of so-called induced systemic tolerance (IST) process (Fig. 2) that involves various physiological and biochemical changes (Yang et al., 2009). It includes modulation of phytohormonal levels (Egamberdieva, 2012; Liu et al., 2013; Glick, 2014; Kang et al., 2014b; Belimov et al., 2015; Cohen et al., 2015) (Fig. 2a), antioxidant defence (Wang et al., 2012; Armada et al., 2014) (Fig. 2b), osmotic adjustment (Sarma and Saikia, 2014) (Fig. 2c), stress responsive genes (Kim et al., 2014) (Fig. 2d), bacterial exopolysaccharides (Vardharajula et al., 2011; Timmusk et al., 2014) (Fig. 2e) and volatile organic compounds (Zhang et al., 2008) (Fig. 2f) that can improve stress tolerance in plants. Kaushal and Wani (2015) has reviewed rhizobacterial-induced drought endurance and resilience (RIDER) mechanisms, however it lacked salinity issues which is a major constraint along with drought characteristic of drylands and recent work. Present review is an attempt to provide an insight on the mechanism exhibited by rhizobacteria that promotes plant growth and

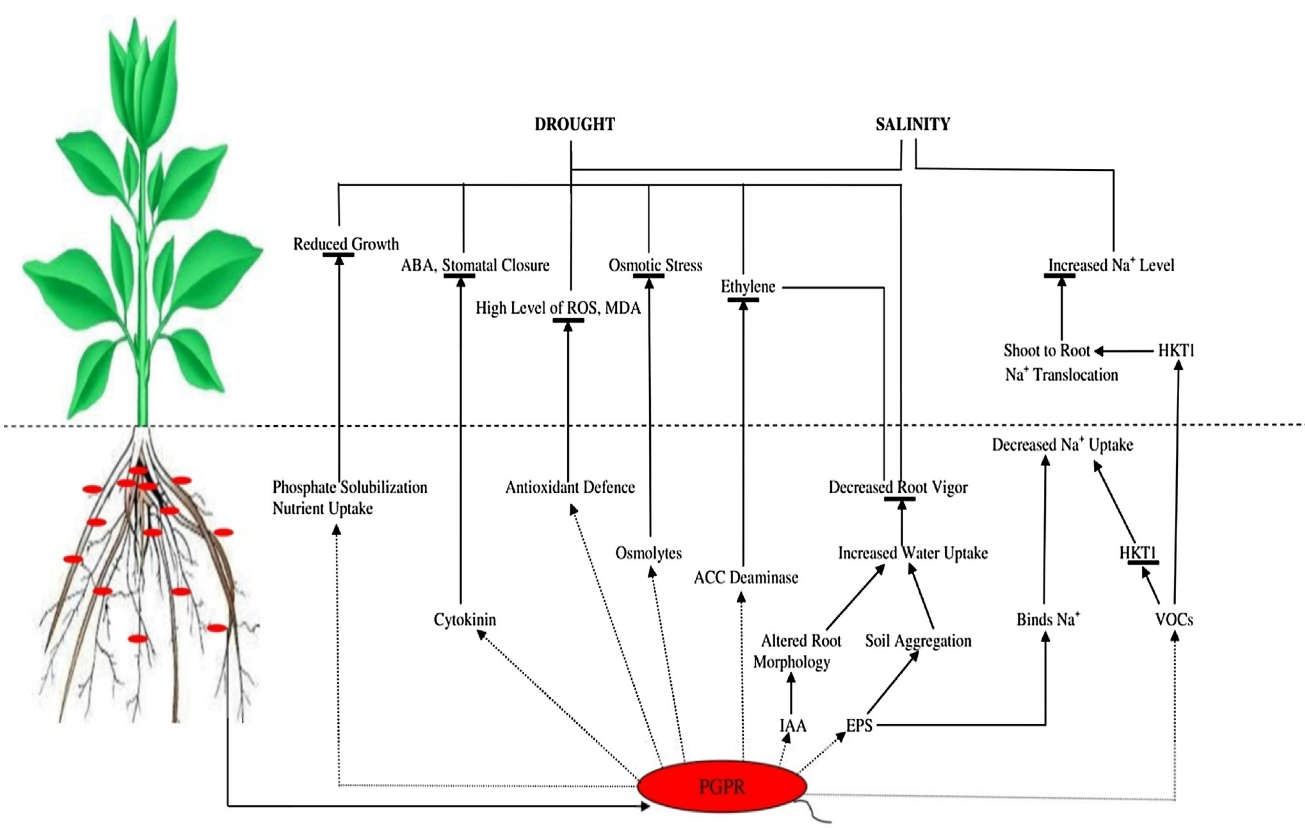

Fig. 1. Plant growth promoting activities exerted by PGPR (rhizobacteria) in relation to the specific mechanisms during drought and salinity stress. Solid arrows indicate drought and salinity stress induced effects on plants; broken arrows indicate rhizobacterial components negating stress effects.
Abbreviations: ABA, abscisic acid; ROS, reactive oxygen species; MDA, malondialdehyde; *HKT1*, high affinity K^+ transporter; ACC, 1-aminocyclopropane-1-carboxylate; VOCs, volatile organic compounds; IAA, indole-3-acetic acid; EPS, exopolysaccharides.